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TECHNICAL NOTE 4014

RECENT RESEARCH ON THE CREEP OF AIRFRAME COMPONENTS

By Eldon E. Mathauser, Avraham Berkovits,
and Bland A. Stein

Langley Aeronautical Laboratory
Langley Field, Va.

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SUMMARY

The results of recent research of the National Advisory Committee for Aeronautics on the creep of airframe components at elevated temperatures are summarized. Experimental lifetime data from creep tests of stainless-steel plates and aluminum-alloy unstiffened circular cylinders are presented and compared with results predicted from isochronous stress-strain curves. The results of a study to determine the magnitude of creep strains that produce significant structural deformations are included. A comparison of structural weight determined from assumed strength and creep criteria is made to establish temperature ranges in which creep is expected to influence structural design for various materials.

INTRODUCTION

Many studies have been made at the National Advisory Committee for Aeronautics during the past few years to obtain basic knowledge of the creep behavior of structural elements at elevated temperatures. These studies have ranged from analytical and experimental investigations of simple structural elements such as columns and plates (refs. 1 to 3) to the development of a variational theorem (ref. 4) suitable for application in many structural creep problems. Studies have also been made to establish approximate methods (for example, ref. 3) for predicting creep collapse of structural components. This paper presents comparisons between experimental and predicted lifetime results for stainless-steel plates and for aluminum-alloy unstiffened circular cylinders. The results of an analysis to determine the magnitude of creep strains that produce significant structural deformations are given. Temperature ranges in which creep is expected to influence aircraft structural design are indicated for various materials.

SYMBOLS

b	width, in.
E_s	secant modulus, ksi
E_t	tangent modulus, ksi
g	acceleration due to gravity, ft/sec^2
k	constant
r	radius, in.
t	thickness, in.
σ_{cr}	critical (buckling) stress, ksi
σ_{cy}	0.2-percent-offset compressive yield stress, ksi
$\bar{\sigma}_f$	average failure stress, ksi

DETERMINATION OF CREEP COLLAPSE

The approximate methods that have been investigated for predicting creep collapse of structural elements are based on the use of isochronous stress-strain curves in conjunction with methods established for predicting maximum strength. An example of isochronous stress-strain curves is given in figure 1. The dashed line indicates the material compressive stress-strain curve for 17-7 PH stainless-steel sheet (condition TH 1,050) at 800° F. The solid lines, designated as isochronous stress-strain curves, indicate the strain produced on application of a given stress plus the creep strain obtained at that stress for the various times. Curves such as these can be obtained by cross plotting compressive creep curves to give stress as a function of strain for different times. The isochronous stress-strain curves shown in figure 1 were obtained from compressive creep tests of the stainless-steel sheet at 800° F. The tick marks indicate the 0.2-percent-offset compressive yield stresses.

Plates

The use of isochronous stress-strain curves for the prediction of creep lifetime of plates will be considered first. A comparison between predicted and experimental lifetimes is shown in figure 2. Applied stress

is plotted against lifetime defined as collapse time for 17-7 PH stainless-steel plates (condition TH 1,050) at 800° F. The symbols indicate compressive-creep-test results from V-groove edge-supported plates for width-thickness ratios ranging from 15 to 60. The solid lines indicate plate life predicted from the following equation:

$$\bar{\sigma}_f = 1.60\sqrt{E_s \sigma_{cy}}\,\frac{t}{b} \tag{1}$$

where $\bar{\sigma}_f$ is the average applied stress to produce creep collapse of the plate, E_s is the secant modulus associated with $\bar{\sigma}_f$, σ_{cy} is the compressive yield stress, and t/b is the plate thickness-width ratio. Equation (1) gives maximum strength of V-groove edge-supported plates at elevated temperatures (ref. 3), if the material parameter $\sqrt{E_s \sigma_{cy}}$ is evaluated from the material compressive stress-strain curve. Evaluation of the material parameter from isochronous compressive stress-strain curves, in general, gives a satisfactory approximation for plate lifetime. This equation has been used to predict creep lifetime for both 2024-T3 and 7075-T6 aluminum-alloy plates. Similar agreement between experimental and predicted results was obtained.

Unstiffened Circular Cylinders

Prediction of creep lifetime of unstiffened circular cylinders using isochronous stress-strain curves will now be considered. In figure 3, bending moment is plotted against lifetime defined as collapse time for 5052-0 aluminum-alloy cylinders at 500° F. The symbols indicate experimental results obtained from reference 5 for radius-thickness ratios ranging from 125 to 250. Predicted lifetimes indicated by the curves were obtained by substituting materials data from isochronous stress-strain curves into the following relation:

$$\sigma_{cr} = k\sqrt{E_s E_t}\,\frac{t}{r} \tag{2}$$

where σ_{cr} is the critical or buckling stress, k is a constant assumed to be 0.6, E_s and E_t are secant and tangent moduli, respectively, and t/r is the cylinder thickness-radius ratio. The predicted buckling stresses were then converted to bending moments by using elementary beam theory. The isochronous stress-strain curves required for this study were obtained from compressive creep tests of 5052-0 aluminum-alloy sheet at 500° F. The experimental results shown in figure 3 are the only data available on the lifetime of cylinders subjected to bending. Although

the predictions are in good agreement with the experimental data, additional studies will be needed to determine whether equation (2) will predict lifetime satisfactorily for cylinders of other materials and to establish the appropriate value of k.

CREEP DEFLECTIONS

The results of the studies of creep of plates and cylinders and of other structural components investigated previously indicate that lifetime defined by collapse can be estimated in general by substituting material data obtained from isochronous compressive stress-strain curves into appropriate relations that define maximum strength of the structural elements. For some types of structures, it is realized that large creep deformations can be obtained in a fraction of the actual collapse time. Such deformations in many cases may determine the useful life of the structure. A study was made accordingly to determine the range of values for creep strain that would be expected to govern design of structures where deformation rather than collapse would be of primary interest.

The structure considered for this study was a constant-stress wing in which the stresses are assumed to be of the same magnitude at all stations along the wing. The deflections of a constant-stress wing are determined from the product of wing configuration and the strains produced by the applied stresses. The deflections that would be produced by creep over a complete range of stress for stainless-steel wings are shown in figure 4. In this figure, stress is plotted against the ratio of wing deflection produced by creep to wing deflection produced by load for 17-7 PH stainless steel at 800° F. Load deflection is defined as the static deflection of the wing obtained immediately upon application of any stress. At a stress of 50 ksi, for example, the creep deflection of the wing in 1 hour is equal to 0.1 of the static or load deflection obtained immediately upon application of the stress. If this stress is applied for approximately 300 hours, the creep deflection increases to a value equal to the static deflection. A shaded area is indicated for the range of creep to load deflection ratios from 0.1 to 1.0. This area is assumed to define the region of interest for structures such as aircraft wings. Creep deflections to the left of the shaded area would be practically negligible; whereas, to the right, the creep deflections would undoubtedly be considered excessive for most structural applications.

Creep strains that are associated with the range of deflection ratios shown in figure 4 are indicated in figure 5. The solid curves have been reproduced from figure 4. The dashed curves indicate creep strains produced in the specified times for the range of stresses shown. Note that creep strains of approximately 0.0002 to 0.002 are associated with ratios

of creep to load deflections ranging from 0.1 to 1.0. These results apply to bending deflections of any constant-stress wing regardless of structural configuration because the ratio of creep deflection to load deflection is determined from the ratio of creep strain to load strain.

This method of analysis which is used to determine the range of creep strains that are of interest for structures subjected to bending was applied to two other materials: 2024-T3 aluminum alloy at 400° F and Inconel X at 1,350° F. The results for the 2024-T3 aluminum alloy are shown in figure 6, and the results for Inconel X are shown in figure 7. For both materials approximately the same range of values of creep strain from 0.0002 to 0.002 was obtained for ratios of creep to load deflections from 0.1 to 1.0.

TEMPERATURE RANGES FOR CREEP

Consideration will now be given to the determination of temperature ranges in which creep will be expected to influence structural design for various materials. These temperature ranges are determined by comparing structural weight required for strength with the weight required for creep at different temperatures. The results obtained from this analysis for stainless steel are presented in figure 8. The required weight of a tensile member in arbitrary units is plotted against temperature for 17-7 PH stainless steel. The solid line indicates the weight required for strength based on ultimate load after 1,000 hours exposure to temperature. Ultimate load is assumed to be 3.75 times the 1 g load. The dashed curves indicate weight required for the three different creep criteria for 1,000 hours at 1 g load; namely, creep strains of 0.0002 and 0.002 and creep rupture.

The dotted curve for 0.0002 creep strain in figure 8 indicates that the tensile member can be designed on the basis of strength up to 650° F. Above 650° F, the weight of the tensile member would increase very rapidly in order not to exceed 0.0002 creep strain. The criterion of 0.002 creep strain would govern the design above 825° F. Above 825° F, significant deflections would be expected to occur in structures subjected to bending as discussed previously. The region between the curve for 0.002 creep strain and the curve for rupture defines the temperature range where creep would be a very important factor in structural design for this material. The region between the two creep-strain lines may be considered to be the temperature range in which creep strains become perceptible and gradually increase to a magnitude that produces significant structural deformations. It is of interest to note that design on the basis of a given creep strain requires a very large increase in weight for small increases in temperature. It appears that it will be more feasible to convert to a higher strength material than to add weight

in order not to exceed a given value of creep strain. If other creep and strength criteria are considered, the position of the creep lines is shifted relative to the strength curve; however, the temperature ranges defined by the distance between the various creep lines remain essentially constant.

This method of analysis of weight required for strength and creep to determine temperature ranges in which creep will be a design consideration was applied to two other materials which are shown in figure 9. The materials considered are 2024-T3 aluminum alloy, 17-7 PH stainless steel and Inconel X. The solid lines indicate the weight required for strength based on ultimate load. The shaded regions define the temperature range for each material where creep may be an important factor in structural design. The width of the shaded regions for each material was established by determining required weight for creep on the basis of several different creep criteria. These results indicate that creep problems will be restricted to a rather narrow range of temperatures for each material and that creep does not become a design consideration until temperatures are reached where the strength of the material deteriorates rapidly. Note that the weight required for creep increases very rapidly with small increases in temperature for all materials considered. It appears that, whenever a temperature is reached where creep is a design consideration, less structural weight will be required by converting to a higher strength material than by designing for creep with the original material. It is realized that conversion to a higher strength material introduces many new problems such as changes in production methods and consideration of availability and strategic importance of the higher strength material. Because of such factors, it is anticipated that the weight of some structural components will be increased to account for material creep rather than converting to a higher strength material.

CONCLUDING REMARKS

The results presented indicate that material creep will influence structural design over a rather narrow range of temperatures for each structural material. In this temperature range, lifetime or collapse time can be estimated satisfactorily for structural elements by using isochronous stress-strain curves in conjunction with established methods for predicting maximum strength. If useful life is determined by deflections rather than collapse, the simplified analysis of creep deflection of constant-stress wings indicates that creep strains ranging from approximately 0.0002 to 0.002 define the region of interest for structures subjected to bending.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 6, 1957.

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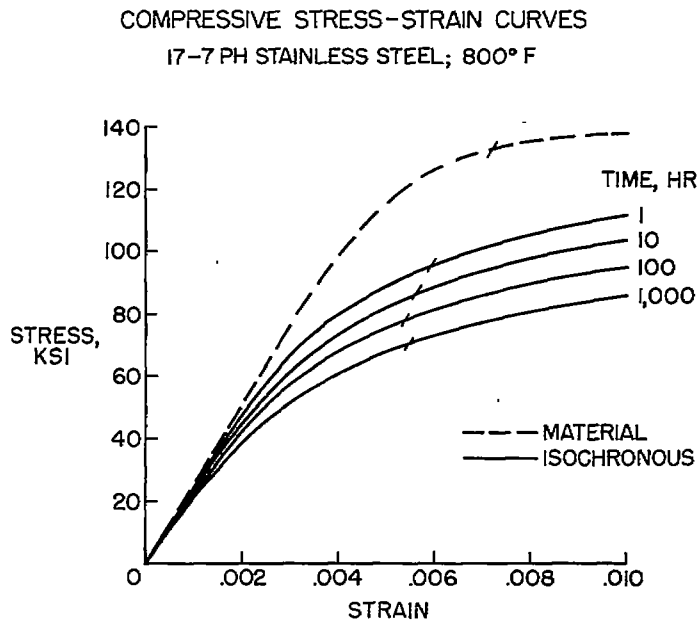


Figure 1

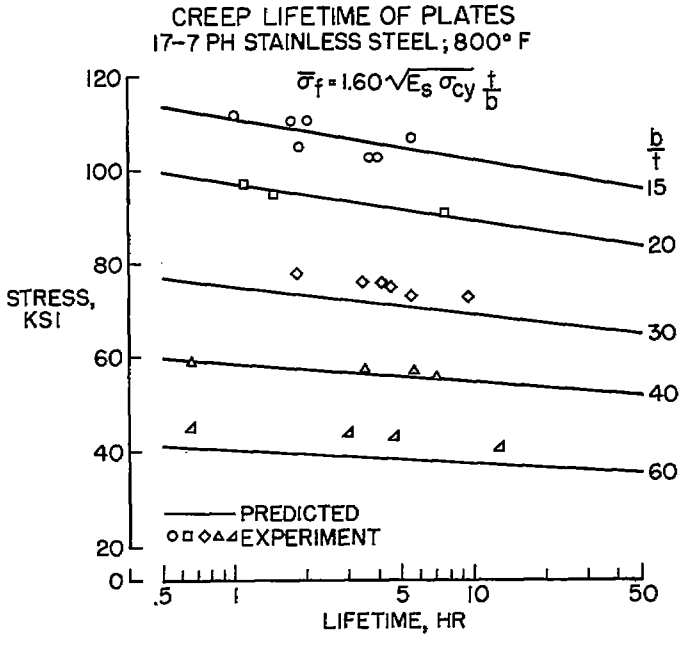
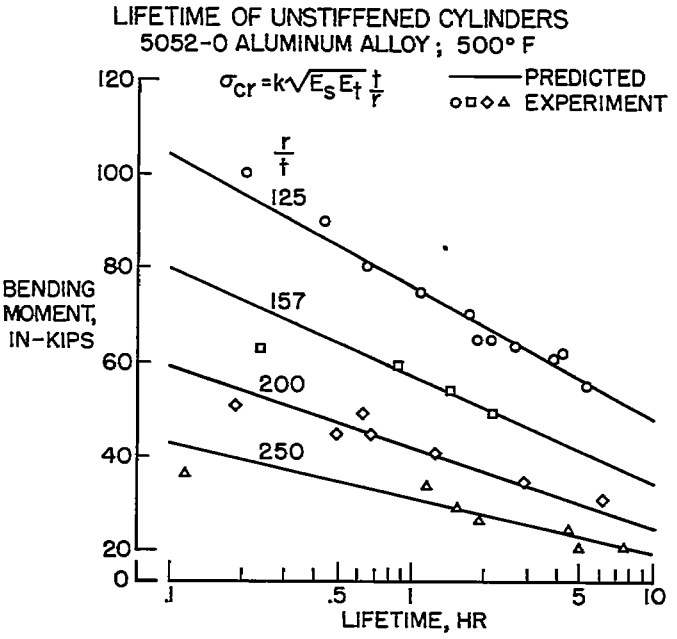


Figure 2



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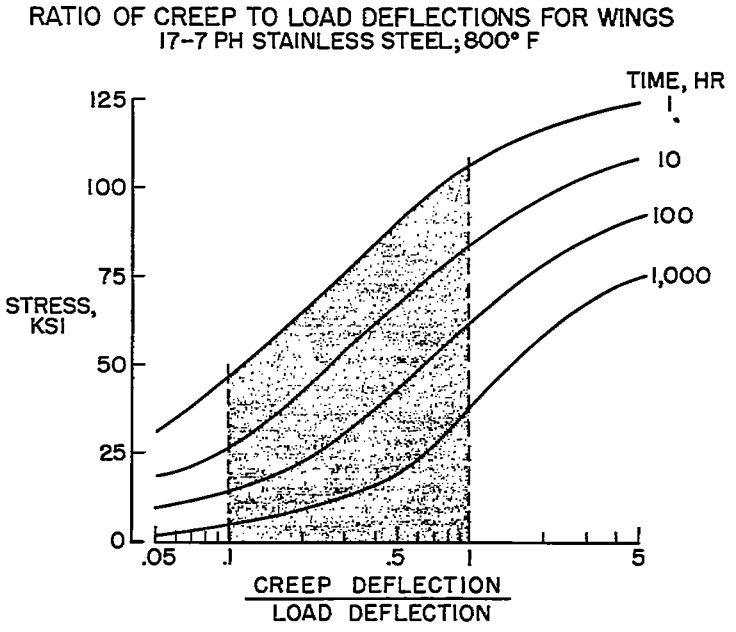
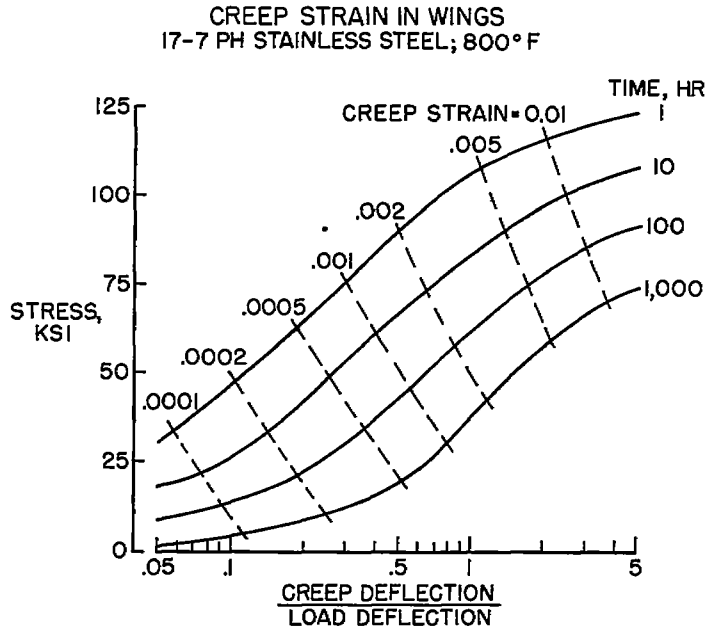


Figure 4



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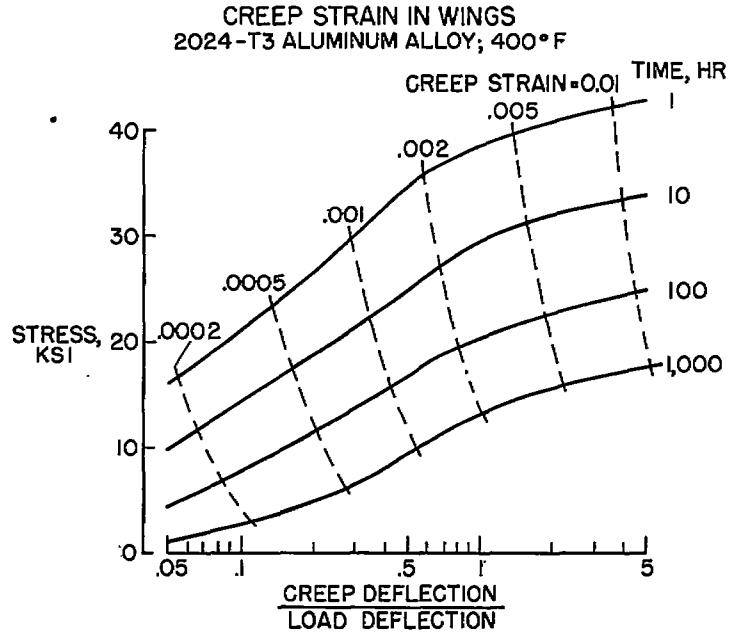
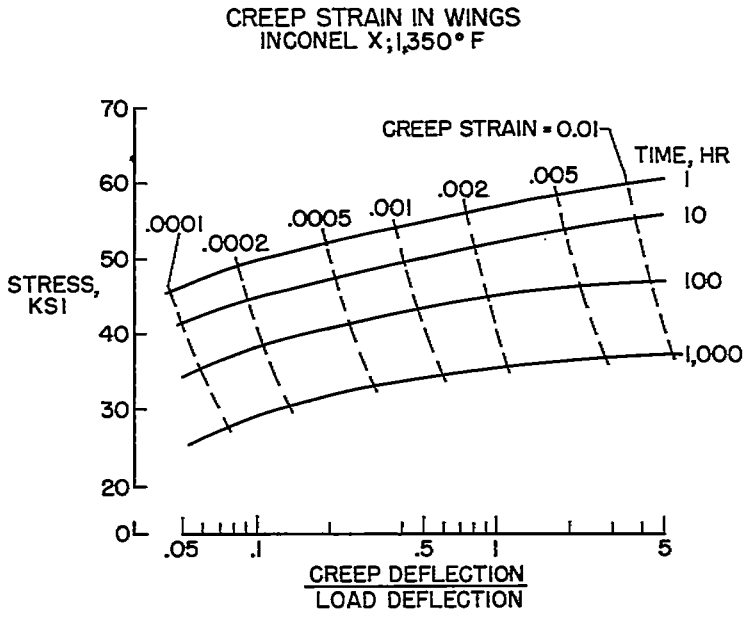


Figure 6



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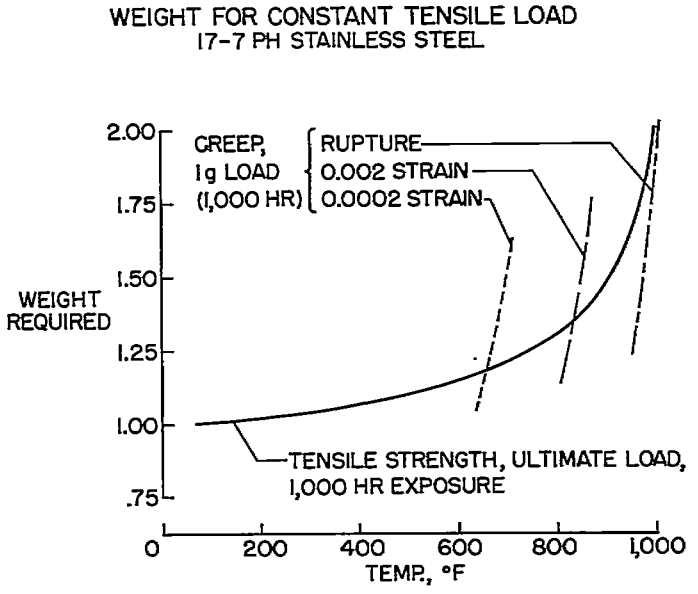

Figure 8

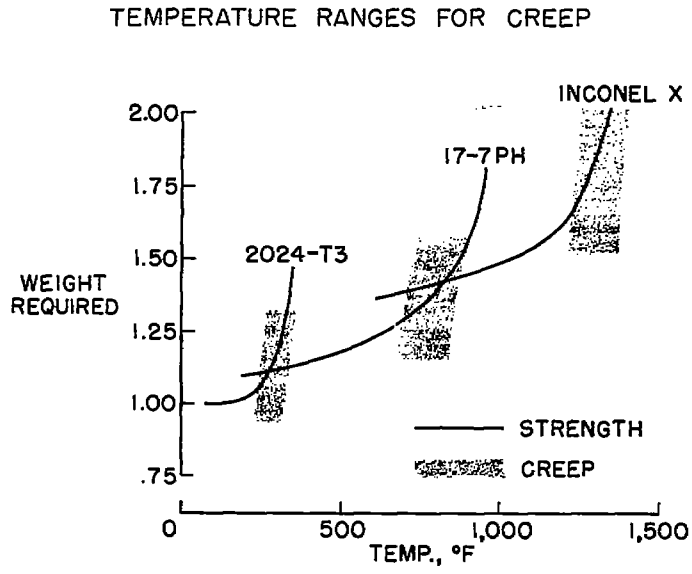
TEMPERATURE RANGES FOR CREEP
INCONEL X
17-7PH
2024-T3
2.00
1.75
1.50
1.25
1.00
.75
WEIGHT REQUIRED
STRENGTH
CREEP
0
500
1,000
1,500
TEMP., °F

Figure 9